DEVELOPMENT AND EVALUATION OF COATINGS FOR THE PREVENTION OF SURFACE OXIDATION AND DECARBURIZATION OF FERROUS MATERIALS DURING HEAT TREATMENT

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By
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to the
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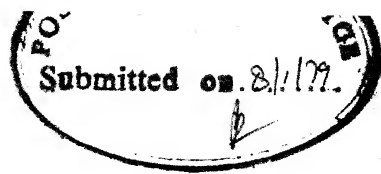TO MY PARENTS

(Late) Dr. K. Kalidas
        K. Annapurnamma.

CERTIFICATE

Certified that the thesis entitled 'Development and Evaluation of Coatings for the Prevention of Surface Oxidation and Decarburization of Ferrous Materials During Heat Treatment' has been carried out under our supervision and the same has not been submitted elsewhere for a degree.
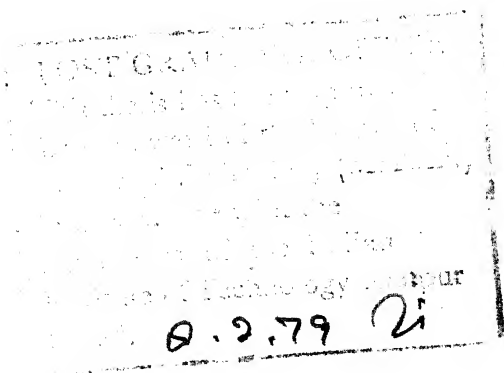
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ABSTRACT

To prevent surface oxidation and decarburization during heat treatment of ferrous materials the controlled atmosphere furnaces and salt baths are conventionally used. They, however, suffer from many inherent disadvantages e.g. high capital cost of the equipment, high cost of salts and inert gases, explosion hazard etc. Most of these disadvantages can be overcome by using surface coatings. Ideally such a coating should meet the following requirements: It should 1) prevent oxidation and decarburization, 2) be easy to apply, 3) be cheap, 4) not hinder heat treatment process, 5) have good thermal conductivity and 6) come off easily after heat treatment process.

Two coating compositions, meeting the above requirements, have been developed after extensive trials. These coatings are able to reduce the oxidation loss of ferrous materials by 65% to 98 %.

CHAPTER I

LITERATURE REVIEW

1.1 INTRODUCTION

Heat treatment is an operation or a combination of operations involving the heating and cooling of metals in the solid state for:

i) hardening and strengthening of metals,

ii) relieving internal stresses, as in castings,

iii) softening objects for further working,

iv) impregnating the metal surface with C, N etc.,

v) obtaining combination of strength and useful ductility,

vi) obtaining desired grain size,

vii) obtaining desired mechanical properties.

Table 1.1 list various heat treatments normally given to ferrous materials.

1.2 PROBLEMS DURING HEAT TREATMENT:

The properties of any material depend on the characteristics of the bulk and those of the surface. Any change in surface characteristics affects a wide variety of material properties. When steels are heat treated in a furnace in the presence of air and combustion products, surface oxidation and

Table 1.1

HEAT TREATMENTS NORMALLY GIVEN TO FERROUS METALS
(Ref. 1 & 2)

S.No.	Material	Heat Treatment	Temp. Range ^oC	Atmospheres or salt Baths commonly used.
1.	Carbon and low alloy steels	Annealing	740-930	(i) Nitrogen (ii) Dissociated ammonia (iii) Exothermic gas mixture e.g. 15% H_2; 10% Co; 5% CO_2; 1% CH_4; and 69% N_2
		Tempering		(i) Endothermic generator gas e.g. 4-5% CO_2; 10-12% CO; 15-18% H_2; a trace to 1% Methane and oxygen
		Martempering	40^oC above austenitization temperature holding at just above M_s or just below M_s temp.	(i) Molten salt baths. e.g. mixture of nitrates such as potassium nitrate and sodium nitrate
		Austempering	Slightly above M_s temp.	(i) Molten Salt Baths NaCl 45-55% + KCl 45-55%

Table 1.1 Contd.

Sl. No.	Material	Heat Treatment	Temp. Range °C	Atmospheres or salt baths commonly used
				(ii) Molten lead
2.	Tool Steel	Normalizing	763 to 872	(i) Ammonia base atmospheres (ii) Endothermic base atmospheres
		Annealing	–do–	–do–
		Austenitizing	763 – 942	(i) Molten Salt baths e.g. Barium chloride, NaCl, CaCl, KCl, etc. nitrates.
		Tempering	121 – 482	–do–
3.	Stainless steel Austenitic stainless steel	Annealing	1010 to 1121	(a) Cracked ammonia (b) Dry purified hydrogen
	Ferritic stainless steel	Annealing	649 to 816	–do–
	Martensitic Stainless Steel	Austenitizing	927 to 1066	–do–
		Annealing	649 to 760	–do–
		Tempering	149 to 371	–do–

Table 1.1 Contd.

Sl No.	Material	Heat Treatment	Temp. Range °C	Atmospheres or salt baths commonly used
4.	High Speed tool steel	Annealing	815 – 900	(a) Cracked ammonia (b) Dry purified hydrogen
		Austenitizing	1204 – 1302	–do–
		Tempering		
5.	Carburized Steel	Single Quench	760 to 872	–do–
		Double Quench	After single quench, again heat it to 871°	–do–
		Tempering	148 to 205	–do–

decarburization occurs. Due to oxidation, surface of the
components becomes rough and dirty. Apart from metal loss
and change in dimentions, this would necessiate cleaning and
machining after the heat treatment is over. However,
machining may be difficult after certain heat treatment,
such as hardening. The carbon content at the surface of
the components also decreases due to decarburization. It
would then be difficult to achieve the desired mechanical
properties at the surface since these properties largly depend
on the carbon content of the steel. Therefore all attempts
are made to minimize oxidation and decarburization during heat
treatment.

OXIDATION: Oxidation of steel is caused by oxygen, carbon
dioxide and/or water vapour as in the following general
reactions[1,2]

$$O_2 + 2Fe \rightleftharpoons 2FeO$$
$$O_2 + 4Fe \rightleftharpoons 2Fe_2O_3$$
$$CO_2 + Fe \rightleftharpoons CO + FeO$$
$$CO_2 + 3FeO \rightleftharpoons Fe_3O_4 + CO$$
$$H_2O + Fe \rightleftharpoons H_2 + FeO$$
$$H_2O + 3FeO \rightleftharpoons H_2 + Fe_3O_4$$
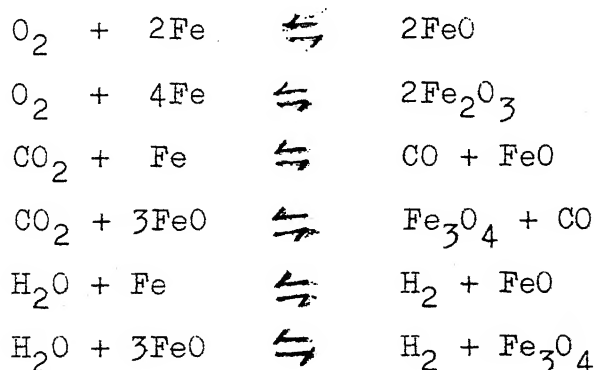
The degree of oxidation or scaling that will be
produced, determined by the equilibrium relationship between

iron and iron oxide in contact with CO and CO_2 or H_2 and water vapour at the heat treating temperatures. The inter-relation of these four gases is known as water gas reaction[3] which may be expressed as:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$
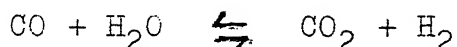
Since furnace atmospheres tend to adjuest themselves at operating temperatures, the above reaction is important. If the furnace atmosphere is too high in CO and low in H_2O another reaction known as producer gas reaction[3] may take place.

$$2CO \rightleftharpoons CO_2 + C$$
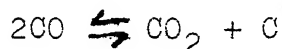
At elevated temperatures steel acts as a catalyst for this reaction which results in the etching or oxidation of bright surfaces and the deposition of soot.

Oxidation of steel may vary from a light adherent straw coloured film which forms at a temperature of about $180^{\circ}C$ to a loose blue - black oxide scale that forms at temperatures above $425^{\circ}C$.

DECARBURIZATION: Decarburization of steel surface occurs upon heating steel to a temperature above $650^{\circ}C$ and proceeds to greater depths below the surface as a function of time, temperature and furnace atmosphere in accordence with the following typical reactions[3,4]:

$$O_2 + C \rightleftharpoons CO_2$$

$$O_2 + Fe_3C \rightleftharpoons 3Fe + CO_2$$

$$CO_2 + C \rightleftharpoons 2CO$$

$$CO_2 + Fe_3C \rightleftharpoons 2CO + 3Fe$$

$$H_2O + Fe_3C \rightleftharpoons CO + H_2 + 3Fe$$
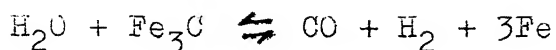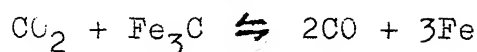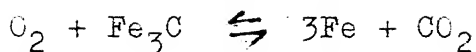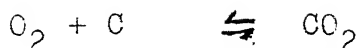
The equilibrium relationship of these reactions are influenced by the ratio of CO and CO_2 which will be neutral to a given carbon content at a given temperature.

1.3 PRESENT METHODS FOR PREVENTING OXIDATION AND DECARBURIZATION DURING HEAT TREATMENT:

To overcome the problems of oxidation and surface decarburization of the ferrous components following methods have been used:

 i) Removal of the oxide scale and decarburized surface by machining after heat treatment.

 ii) Applications of an electroplated coating ($12.7\mu - 25.4\mu$). Usually of copper, prior to heat treatment.

 iii) Heating parts in a sealed steel box packed in charcoal or cast iron chips,

 iv) Use of molten salt baths as heating media,

 v) Use of protective furnace atmospheres.

By removing the decarburized surface by machining the metal loss during heat treatment can not be prevented, and may not be a desirable remedy in most cases.

By electroplating copper on steel the oxidation and decarburization can be prevented. This is, however, not economical since copper is a costly metal and its removal after the heat treatment might create problems. Moreover, copper itself gets oxidized in some cases[3].

By sealing the parts to be heat treated in steel box, the parts can be heat treated without oxidation and decarburization. But it is not a convenient solution to the problem. Apart from the extra operations of packing, removing and cleaning the parts, the steel container will oxidize and desintegrate. This would necessiate its replacement after few heat treatment cycles.

Rapid heat transfer for austenetizing and tempering semifinished or finished machine parts will be provided by molten salt baths with adequate protection against oxidation and decarburization, provided the composition of the bath is regularly controlled. Certain limitation[2,3,4] such as

    i) availability of salts,

   ii) salts are mildly oxidizing and decarburizing to steels at heat treatment temperatures,

  iii) periodic rectification of salts is necessary,

iv) limitations on operating temperature range,

v) the difficulty of quenching parts with blind holes etc. restrict the use of salt baths for heat treatment.

At present the application of protective furnace atmospheres is widespread for heat treatment of steels. Typical protective atmospheres used in industry for preventing oxidation and decarburization are[1-3]

i) Hydrogen,

ii) Nitrogen,

iii) Argon,

iv) Helium,

v) Dissociated ammonia,

vi) Exothermic gas,

vii) Endothermic gas

Table 1.2 shows the gases generally found in protective atmospheres and their reaction with iron and iron oxide.

Some of the draw backs of the protective atmosphere furnaces are[2-10].

i) Initial cost of the equipment needed is high,

ii) Cost of the gases used is usually very high,

iii) They have strong decarburizing potential,

iv) They are explosive in contact with air,

Table: 1.2

GASES COMMONLY FOUND IN PROTECTIVE FURNACE ATMOSPHERES AND THEIR REACTIONS WITH IRON AND IRON CARBIDE[3]

Gas	Reactions		
	The gas comb-ining with	to from	R e a c t i o n
Nitrogen		Neutral	
Oxygen	Iron	Iron Oxide	Strongly Oxidizing
	Iron Carbide	Iron	Strongly Decarburizing
Carbon Dioxide	Iron	Iron Oxide	Strongly Oxidizing
	Iron Carbide	Iron	Strongly decarburizing
Water Vapour	Iron	Iron Oxide	Oxidizing
	Iron Carbide	Iron	Strongly Decarburizing
Hydrogen	Iron oxide	Iron	Strongly reducing
Carbon Monoxide	Iron	Iron Carbide	Strongly Carburizing
	Iron Oxide	Iron	Reducing.
Methane	Iron	Iron Carbide	Strongly Carburizing
	Iron Oxide	Iron	Reducing

v) They could result in hydrogen embrittlement of certain steels,

vi) They tend to damage thermocouples and decrease the life of the furnace resistors.

vii) Atmospheres containing CO may cause rapid and serious disintegration of refractory brick work, etc.

1.4 SURFACE COATINGS FOR PREVENTING OXIDATION AND DECARBURIZATION DURING HEAT TREATMENT

Apart from the many disadvantages listed earlier, associated with salt bath and protective atmosphere furnaces, it may be either difficult, when the component size is too large, or uneconomical, when the frequency of use is less, to use these furnaces. In such cases use of a protective coating which can be directly applied on the component surface would be ideal.

The advantages of using such a coating will include the following:

1. It will be possible to use ordinary furnaces without any modification.

2. There will be no need to observe additional safety precautions which have to be normally observed in maintaining the protective atmosphere and salt bath furnaces.

3. There will be no explosion hazard.

4. The life of the thermocouples and furnace resistors will
    be increased.

Such a coating ideally should:

1. be able to prevent surface oxidation and decarburization
    of the component.

2. be cheap.

3. be easy to apply.

4. easily come off from the component surface after the
    heat treatment is over.

5. have good thermal conductivity.

6. not hinder with the normal heat treatment cycle for the
    given metal.

In a British patent[11] it has been claimed that the
oxidation rate of steel billets at 1280°C was reduced from
180 mg/cm^2 to 20 mg/cm^2 when they were coated prior to heat
treatment with a mixture of polyvenylacetate with water containing
powders of aluminium and a divalent metal oxide such as ZnO,
MgO. Using sodium-alluminate Cr_2O_3, SiO_2, sodium polycrylate
and water as coating composition Higuchi et. al.[12] succeded
in decreasing the oxidation rate of 9% Ni steel from 371
mg/cm^2 to 171 mg/cm^2 at 1200°C for 3 hrs. Several other
investigators[13-25] have also claimed that coatings containing
Al_2O_3, SiO_2, Na_2O, B_2O_3 CaO, MnO etc with different carriers
of powders such as silicates, phosphates, bakelite, dextrin

etc. reduce the oxidation and decarburization of steel
during heat treatment. No information was, however, available
regarding the actual composition, oxidation rate and other
desirable coating properties listed earlier.

CHAPTER II

EXPERIMENTAL

2.1 MEASUREMENT OF OXIDATION LOSS

Oxidation loss at different temperatures was determined using specimens of mild steel, stainless steel and tool steel (Table 2.1). Surface oxide from the specimens was removed by using a suitable cleaner (Table 2.1).

The raw materials used for coating were ground in a ball mill, for 12 hours using 1/2" and 1" dia balls. Sieve analysis before and after grinding is given in Table 2.2.

20 gm of the coating powder was mixed with 12 cc of the binder into a smooth paste. This was then applied to the cleaned specimen surface using a paint brush.

The coated specimens were air dried and charged in the furnace either at room temperature or at elevated temperature to determine the oxidation loss.

Any loose oxide on the specimen surface, after exposure at high temperature, was first cleaned. If necessary the specimens were cleaned by pickling.

2.2 DECARBURIZATION

Coated and uncoated specimens of 0.56 % C steel (Table 2.1) were charged in the furnace at $1000^{o}C$ for 10 hours followed by air cooling. Specimen cross-section was prepared for metallographic examination.

Table 2.1

MATERIAL'S CHEMICAL COMPOSITION AND THE PICKLING AGENTS USED

Sl. No.	Material	Chemical Composition weight percentage	Pickling solution composition	Metal attack in 1 minute mg/cm^2
1	Mild steel	C-0.2, Si-0.11, P-0.02, S-0.01, Mn-0.72	1:1 HCl acid	0.04
2	Stainless steel	C-0.1, Cr-1'.9, Ni-11.4	5 by vol. HF+ 20 by vol. HNO_3 + 75 by vol. water	Nil
3	Tool steel	C-0.7, Cr-4.2, V-1.0, Mo-0.33, W-6.0	1:1 HCl acid	Nil
4	Carbon steel	C-0.56, Si-0.11, P-0.02, S-0.01, Mn-0.72	1:1 HCl acid	0.04

Table 2.2

SHIEVE ANALYSIS OF MATERIALS BEFORE AND AFTER GRINDING

Mesh	A wt% No grinding	B wt% No grinding	C wt% Before grinding	C wt% After grinding	D wt% Before grinding	D wt% After grinding	E wt% Before grinding	E wt% After grinding
- 10 + 60	—	—	100.0	—	50.0	—	2.0	—
- 60 +100	—	—	—	—	10.0	—	2.0	—
-100 +140	—	—	—	—	10.0	—	28.0	—
-140 +200	—	—	—	—	10.0	—	42.0	—
-200	—	—	—	—	20.0	—	26.0	—
-200 +270	—	—	—	9.0	—	7.0	—	2.5
-270 +325	—	—	—	6.0	—	5.0	—	4.0
-325 +400	—	—	—	6.0	—	13.0	—	3.0
-400	100.0	100.0	—	78.0	—	75.0	—	90.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Surface turnings in steps of 0.127mm upto a depth
of 1.143mm were removed for chemical analysis.

2.3 THERMAL CONDUCTIVITY OF THE COATING

Thermal conductivity of the coating was estimated
by measuring the rise in core temperature of 25 cm diameter
mild steel bar. The coated and uncoated specimens were charged
at room temperature and the furnace temperature was allowed
to rise to 1000°C. Good thermal conductivity of the coating
would be reflected by a time lag in core temperature rise
of coated specimen.

2.4 EFFECT OF COATING ON THE HARDENING TREATMENT

Coated and uncoated 0.56 %C steel specimen (Table 2.1)
were austenitized at 1000°C for 1 hour followed by water
quenching. Specimen cross-section was prepared for micro-
hardness measurement.

CHAPTER III

RESULTS AND DISCUSSION

3.1 EFFECT OF BINDER COMPOSITION

It was evident from the literature survey that the nature of the binder has an important influence on the coating properties. Several materials were therefore evaluated for their suitability as binders (Table 3.1). Minimum oxidation loss of mild steel at $800^{\circ}C$ for 5 hrs was observed when binder 'S' having a specific gravity of 1.2 gm/c.c. was used (Figure 1, Table 3.2).

3.2 EFFECT OF COATING COMPOSITION AND SPECIFIC GRAVITY OF THE BINDER

Initially several coating compositions were tried using binder 'S' having a specific gravity of 1.3 gm/c.c. The results showed that whereas the oxidation loss of uncoating mild steel specimen at $1000^{\circ}C$ for 5 hrs was 152 mg/cm^2, it was possible to reduce it upto a value of 24.035 mg/cm^2 using coating composition GC3 (Table 3.3, Table 3.4). However during the coarse of the investigation it became evident that the specific gravity of the binder 'S' was having an influence on the coating properties. In order to determine the optimum value, the specific gravity of the binder was changed between 1.1 and 1.4 gm/c.c. Using coating composition

Table 3.1

BINDER CODE AND THEIR PREPARATION

Binder Code No.	Method of Preparation
S	Either 60 gms or 75 gms of the binder 'S' were dissolved in 100 cc of boiled water to get binder solution having a specific gravity of 1.2 gm/cc or 1.3 gm/cc respectively.
A	30 gms of binder 'A' of -270 mesh was ball milled with 140 gms of 85 orthosphoric acid for 1 hr. Then 30 gms of binder 'A' was added and ball milled for 2 hrs. 150 gms of water was added and milled for 15 mins. after 2 hrs. milling. Then the slurry was kept 42 hrs to settle in a beaker. 2.4 gms of Cr_2O_3 in 20 ml of water was added to the settled mass after clearing the clean solution over the settled mass.
P	4 gms of binder 'P' was dissolved in 100 cc of warm water.

Table 3.2

EFFECT OF BINDER COMPOSITION ON THE OXIDATION
LOSS OF MILD STEEL AT 800°C FOR 5 Hrs USING
COATING GC4*

Sl. No.	Binder Code	Oxidation Loss (mg/cm^2)
1.	S	3.94
2.	A	24.11
3.	P	38.28

* In all cases the coated specimens were air
  dried for 6 hrs and charged in the furnace
  at room temperature.
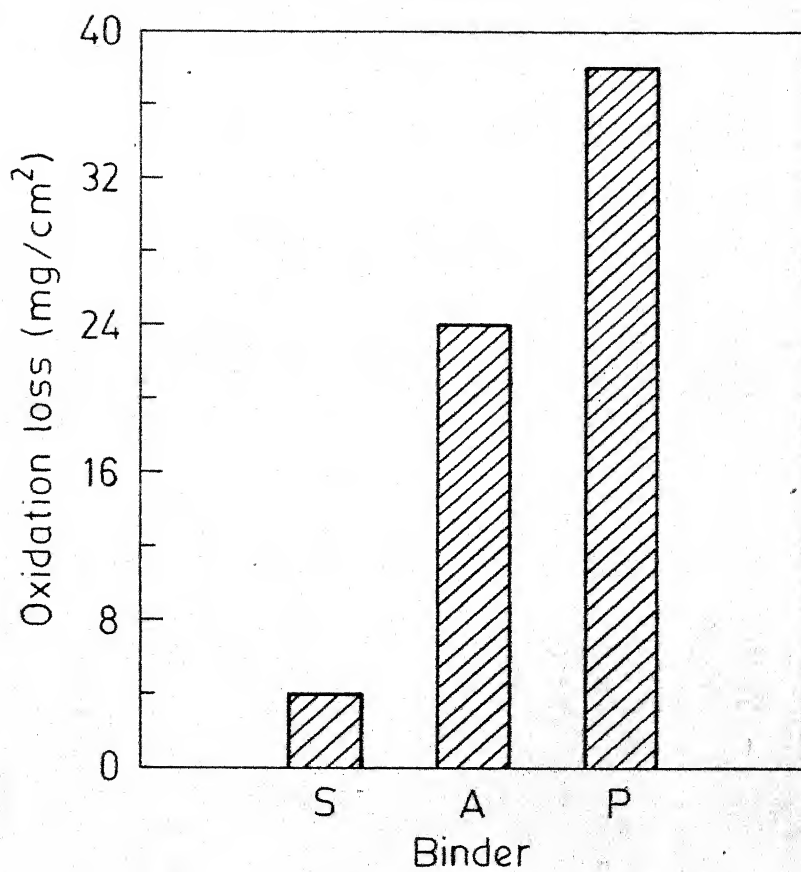
Fig. 1 Effect of binder composition on the oxidation loss of mild steel at 800° C for 5 hrs using coating GC 4.

COATING COMPOSITION

		Weight percentage of components								
Sl. No.	Composition Code	A	B	C	D	E	F	G	H	I
1	2	3	4	5	6	7	8	9	10	11
1	GC1	65.0	-	15.0	-	-	-	-	20.0	-
2	GC2	30.0	-	10.0	10.0	-	50.0	-	-	-
3	GC3	20.0	10.0	10.0	30.0	-	30.0	-	-	-
4	GC4	20.0	10.0	10.0	30.0	30.0	-	-	-	-
5	GC5	-	25.0	-	15.0	25.0	25.0	10.0	-	-
6	GC6	-	40.0	-	40.0	-	-	-	-	20.0
7	MN1	26.6	10.0	10.0	26.7	26.7	-	-	-	-
8	MN2	12.0	"	"	12.0	56.0	-	-	-	-
9	MN3	56.0	"	"	12.0	12.0	-	-	-	-
10	MN4	12.0	"	"	56.0	12.0	-	-	-	-
11	MN5	34.0	"	"	34.0	12.0	-	-	-	-
12	MN6	12.0	"	"	34.0	34.0	-	-	-	-
13	MN7	34.0	"	"	12.0	34.0	-	-	-	-
14	MG1	26.6	"	"	26.7	-	26.7	-	-	-
15	MG2	12.0	"	"	12.0	-	56.0	-	-	-
16	MG3	56.0	"	"	12.0	-	12.0	-	-	-

Table 3.3 (Contd.)

1	2	3	4	5	6	7	8	9	10	11
17	MG4	12.0	10.0	10.0	56.0	-	12.0	-	-	-
18	MG5	34.0	"	"	34.0	-	12.0	-	-	-
19	MG6	12.0	"	"	34.0	-	34.0	-	-	-
20	MG7	34.0	"	"	12.0	-	34.0	-	-	-
21	CR1	26.6	"	"	26.7	-	-	26.7	-	-
22	CR2	12.0	"	"	12.0	-	-	56.0	-	-
23	CR3	56.0	"	"	12.0	-	-	12.0	-	-
24	CR4	12.0	"	"	56.0	-	-	12.0	-	-
25	CR5	34.0	"	"	34.0	-	-	12.0	-	-
26	CR6	12.0	"	"	34.0	-	-	34.0	-	-
27	CR7	34.0	"	"	12.0	-	-	34.0	-	-

Table 3.4

EFFECT OF COATING COMPOSITIONS USING BINDER 'S' OF 1.2 gms/cc SPECIFIC GRAVITY ON THE OXIDATION LOSS OF MILD STEEL AT 1000°C FOR 5 hrs*

Expt. No.	Composition Code	Oxidation Loss mg/cm^2	Visual Observation	
			After Air drying for 6 hrs	After firing
1	GC1	38.77	B	G
2	GC2	65.60	A	D
3	GC3	24.04	C	D
4	GC4	28.60	A	D
5	GC5	24.94	B	G
6	GC6	43.00	B	D
7	MN1	8.01	C	D
8	MN2	22.93	C	E
9	MN3	23.52	C	E
10	MN4	10.23	C	D
11	MN5	33.97	A	E
12	MN6	44.81	B	E
13	MN7	28.59	C	E
14	MG1	55.86	B	F
15	MG2	86.37	B	G
16	MG3	49.11	B	E
17	MG4	32.95	B	E
18	MG5	40.98	B	F
19	MG6	23.80	B	E
20	MG7	33.72	B	E

Table 3.4 (Contd.)

Expt. No.	Composition Code	Oxidation Loss mg/cm^2	Visual Observation	
			After Air drying for 6 hrs	After firing
21	CR1	23.71	B	E
22	CR2	22.97	B	E
23	CR3	25.03	B	E
24	CR4	34.48	B	E
25	CR5	60.83	B	F
26	CR6	43.36	B	E
27	CR7	54.24	B	F

*   - 12 cc of the binder was mixed with 20 gms of Coating Powder.

- After firing at high temperature the coating came off in all cases from the specimen surface during cooling.

- Visual observation code.

A - Uneven surface, heavily cracked indicating that the coating has poor paintability and poor adherence to the base.

B - Even surface, slightly cracked at the edges indicating that the coating has moderate paintability and adherence to the base.

C - Even surface, no cracks indicating good paintability and strong adherence to the base.

D - Slight oxidation without pitting.

E - Light gray colour, slightly pits are formed.

F - Dark black coloured oxidation layer which comes off as flakes.

G - Dark gray colour, heavily pitted.

GC 3, the oxidation loss of mild steel at all temperature s decreased rapidly on increasing the specific gravity of the binder upto 1.3 gm/c.c. Beyond this value there was practically no effect at all temperatures. (Figure 2, Table 3.5). Further experimental work was therefore carried out using binder 'S' having a specific gravity of 1.3 gm/c.c.

Several other coating compositions were tried in an attempt to further reduce the oxidation loss. It was observed that using coating compositions MN1 and MN4 the oxidation loss was only 8 and 10 mg/cm^2 (Table 3.4). It was therefore, decided to evaluate these two coating compositions on a variety of ferrous materials at different temperatures and times.

3.3 OXIDATION PREVENTION OF MILD STEEL

Effectiveness of coating compositions MN1 and MN4 using binder 'S' of 1.3 gm/cc specific gravity in preventing oxidation loss of mild steel at different temperatures for different times was determined.

Comparing oxidation loss of uncoated mild steel (Figure 3, Table 3.6) with mild steel coated with coating compositions MN1 and MN4 (Figure 4, Table 3.6) and percentage reduction in oxidation loss using these coatings MN1 and MN4 (Figure 5, Table 3.7) following could be observed:

Table 3.5

EFFECT OF SPECIFIC GRAVITY OF THE BINDER 'S' ON OXIDATION LOSS OF MILD STEEL IN 5 Hrs AT DIFFERENT TEMPERATURES USING COATING GC3*

Expt. No.	Firing Temperature °C	Oxidation Loss (mg/cm^2) Binder Specific Gravity and gms/cc			
		1.1	1.2	1.3	1.4
1	1000	33.70	22.00	10.76	15.55
2	900	22.79	21.20	9.99	6.21
3	800	21.94	16.95	5.30	3.47

*   - 12 cc of the binder was mixed with 20 gms of coating powder.

       - In all cases the coated specimens were air dried for 6 hrs. and charged in the furnace at room temperature.

       - In all cases the coating surface after air drying was even with no cracks indicating **goo**d paintability and adequate adherence to the base.

       - After firing at high temperature the coating came off in all cases from the specimen surface during cooling.
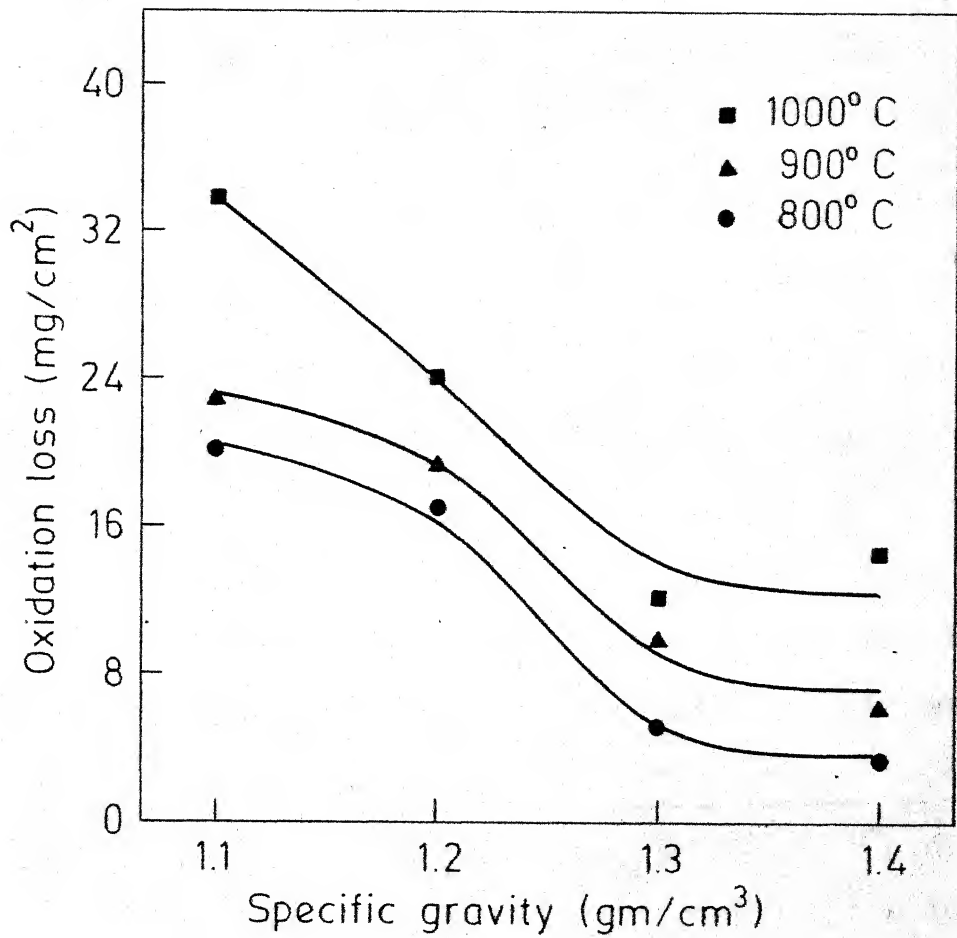
Fig. 2 Effect of specific gravity of the binder on the oxidation loss of mild steel exposed at different temperatures for 5 hours.

Table 3.6

OXIDATION LOSS OF MILD STEEL AT DIFFERENT TEMPE-
RATURES AND TIMES WITH AND WITHOUT COATING *

Expt. No.	Coating Code	Time hrs	Oxidation Loss (mg/cm^2) at temperature		
			700°C	800°C	1000°C
1	Uncoated	2.5	6.00	41.35	97.00
2	''	5.0	14.55	54.36	151.90
3	''	7.5	28.98	88.05	298.86
4	''	10.0	46.24	105.28	398.57
5	MN1	2.5	1.79	1.75	8.47
6	''	5.0	3.25	2.01	9.97
7	''	7.5	2.87	6.39	19.80
8	''	10.0	8.53	4.89	22.52
9	MN4	2.5	4.17	5.50	8.61
10	''	5.0	4.45	8.67	18.19
11	''	7.5	3.95	5.02	10.14
12	''	10.0	4.68	5.68	12.84

*   - 12 cc of binder 'S' having a specific gravity of 1.3 gm/cc was mixed with 20 gms of coating powder.

        - Coated specimens were air dried for 6 hrs at room temperature before exposure at high temperature.
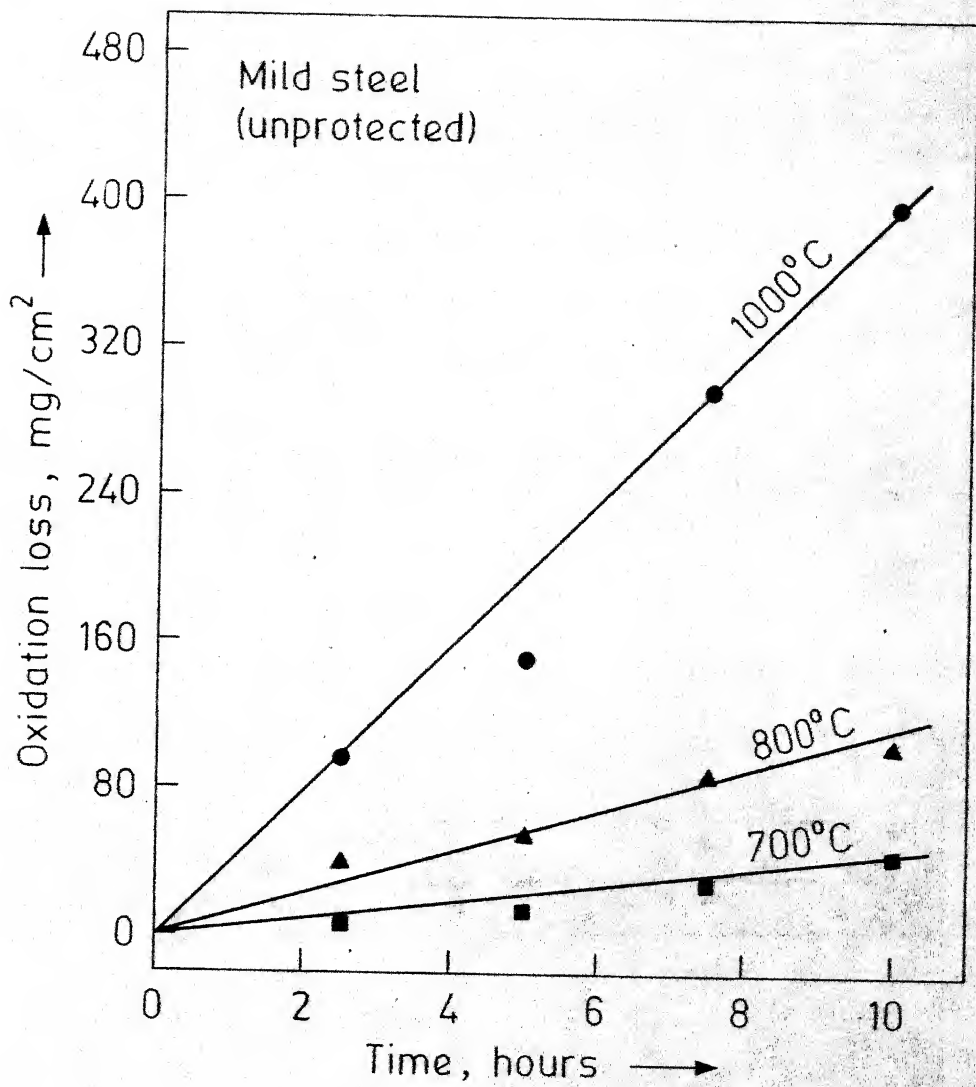
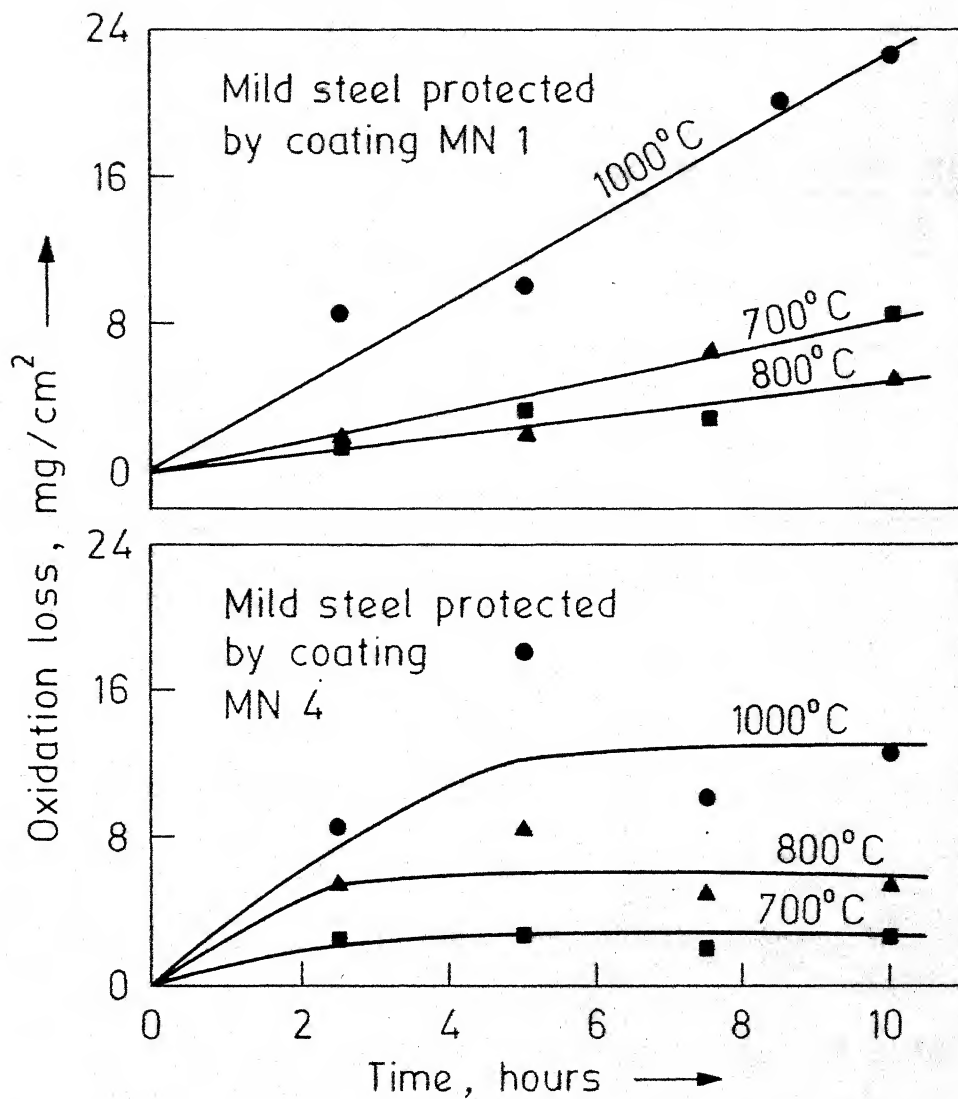Fig. 3 Oxidation loss of unprotected mild steel at different temperatures and times.

Fig. 4 Oxidation loss of mild steel protected by coatings MN 1 and MN 4 at different temperatures and times.

Table 3.7

PERCENTAGE REDUCTION IN OXIDATION LOSS OF MILD STEEL EXPOSED
AT DIFFERENT TEMPERATURES AND TIMES USING COATINGS MN1 & MN4*

Time Hrs.	% Reduction in Oxidation Loss of Mild Steel Using					
	Coating MN1 at			Coating MN4 at		
	700°C	800°C	1000°C	700°C	800°C	1000°C
2.5	70.17	95.77	91.27	30.50	86.70	91.12
5.0	77.66	96.30	93.44	69.42	84.03	88.03
7.5	90.10	92.74	93.37	86.37	94.30	96.61
10.0	81.55	95.36	94.34	89.88	94.80	99.69

* - 12.cc. of binder S having a specific gravity of 1.3gm/cc.
was mixed with 20 gms of coating powder.

- Coated specimens were air dried for 6 hrs at room
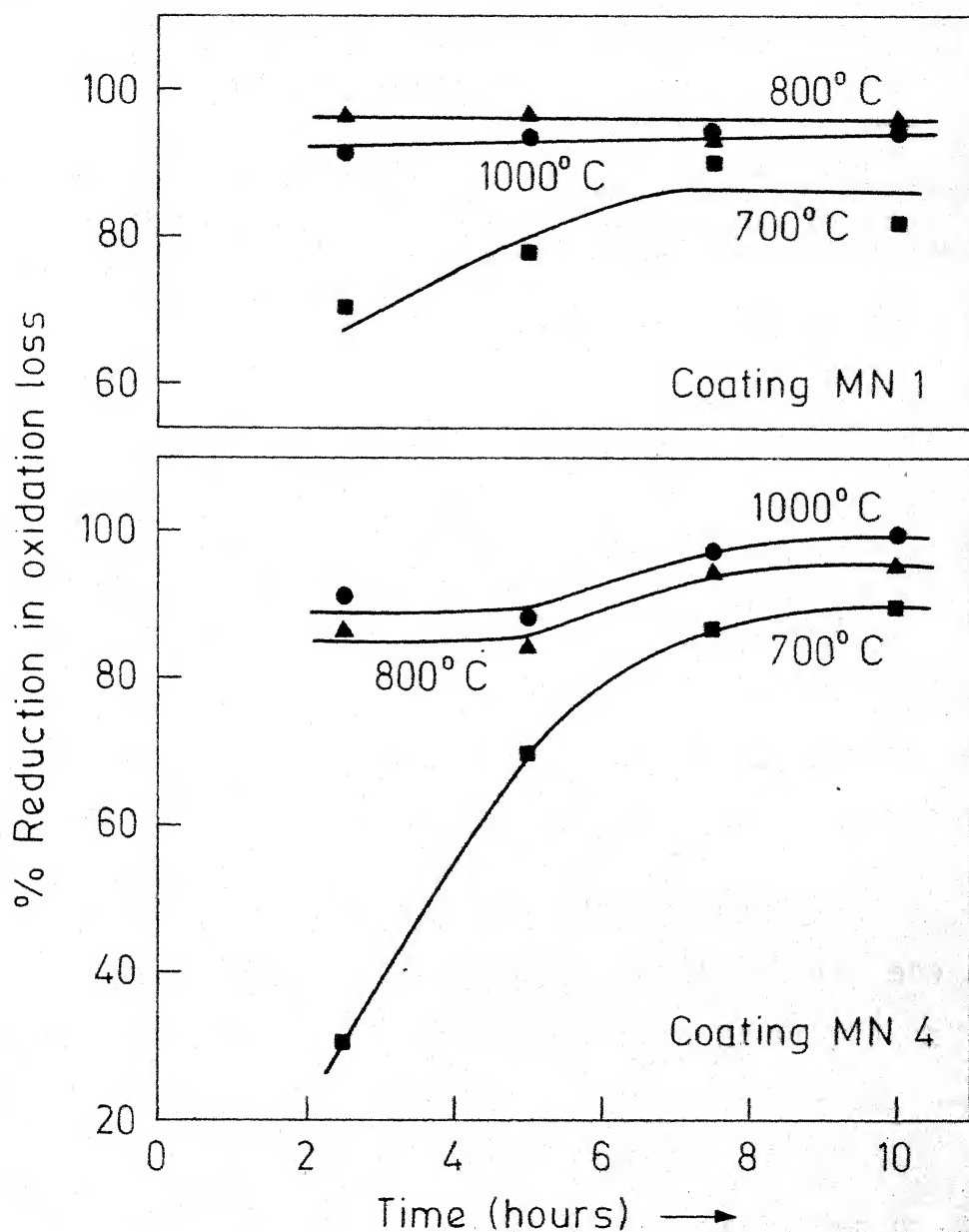temperature before exposure at high temperature.

Fig. 5 Effectiveness of coatings MN 1 and MN 4 in reducing oxidation loss of mild steel at different temperatures and times.

i)   Both coatings MN1 and MN4 were very effective in
     reducing oxidation loss of mild steel at all tempera-
     tures and times. At higher temperatures and longer
     times the coatings are effective in reducing oxida-
     tion loss by above 95 %.

ii) Effective ness of the coatings in preventing oxidation
     loss, increase s with exposure time at all temperatures,
     the effect being more pronounced at $700^{o}C$.

iii) At lower temperatures, say $700^{o}C$, for shorter exposure
     periods coating MN1 was more effective in reducing
     oxidation loss, whereas for longer exposure periods
     coating MN4 was more effective.

3.4   OXIDATION PREVENTION OF STAINLESS STEEL

Effectiveness of coating compositions MN1 and MN4
using binder 'S' of 1.3 gm/c.c. specific gravity in preventing
oxidation loss of 18-8 stainless steel at different tempera-
tures for different times was determined.

Comparing oxidation loss of uncoated 18-8 stainless
steel (Figure 6, Table 3.8) with specimens protected by
coatings MN1 and MN4 (Figure 7, Table 3.8) and percentage
reduction in oxidation loss using these coatings (Figure 8,
Table 3.9) following can be observed:

Table 3.8

OXIDATION LOSS OF STAINLESS STEEL AT DIFFERENT TEMPERATURES
AND TIMES WITH AND WITHOUT COATING*

Expt. No.	Composition Code	Time hrs.	Oxidation Loss (mg/cm^2) at temperature			
			900°C	1000°C	1100°C	1200°C
1	Uncoated	2.5	5.74	18.65	48.90	76.00
2	' '	5.0	9.13	24.90	43.88	111.94
3	' '	7.5	22.06	22.45	68.42	152.50
4	' '	10.0	23.03	34.25	88.00	160.94
5	MN1	2.5	0.00	0.04	1.46	3.43
6	' '	5.0	0.00	0.11	1.83	3.38
7	' '	7.5	0.00	0.34	2.83	11.20
8	' '	10.0	0.00	0.55	6.45	16.52
9	MN4	2.5	0.00	0.21	1.43	6.23
10	' '	5.0	0.00	1.92	1.96	11.42
11	' '	7.5	0.00	1.99	2.31	10.00
12	' '	10.0	0.00	3.76	2.75	12.25

*   - 12 cc of binder S having a specific gravity of 1.3 gm/cc was mixed with 20 gms of coating powder.

       - Coated specimens were air dried for 6 hrs at room temperature before exposure at high temperature.
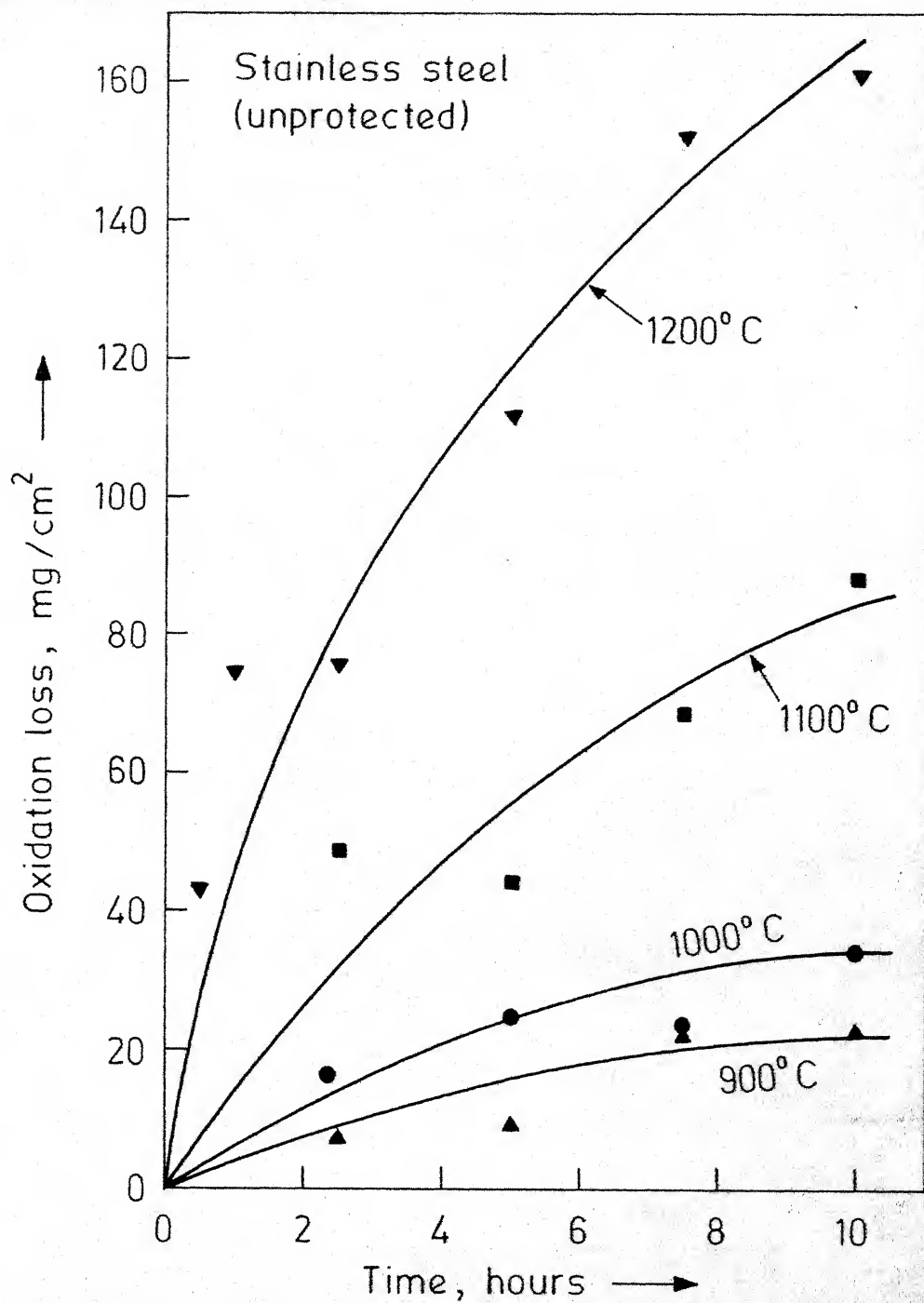
Fig. 6 Oxidation loss of unprotected stainless steel at different temperatures and times.
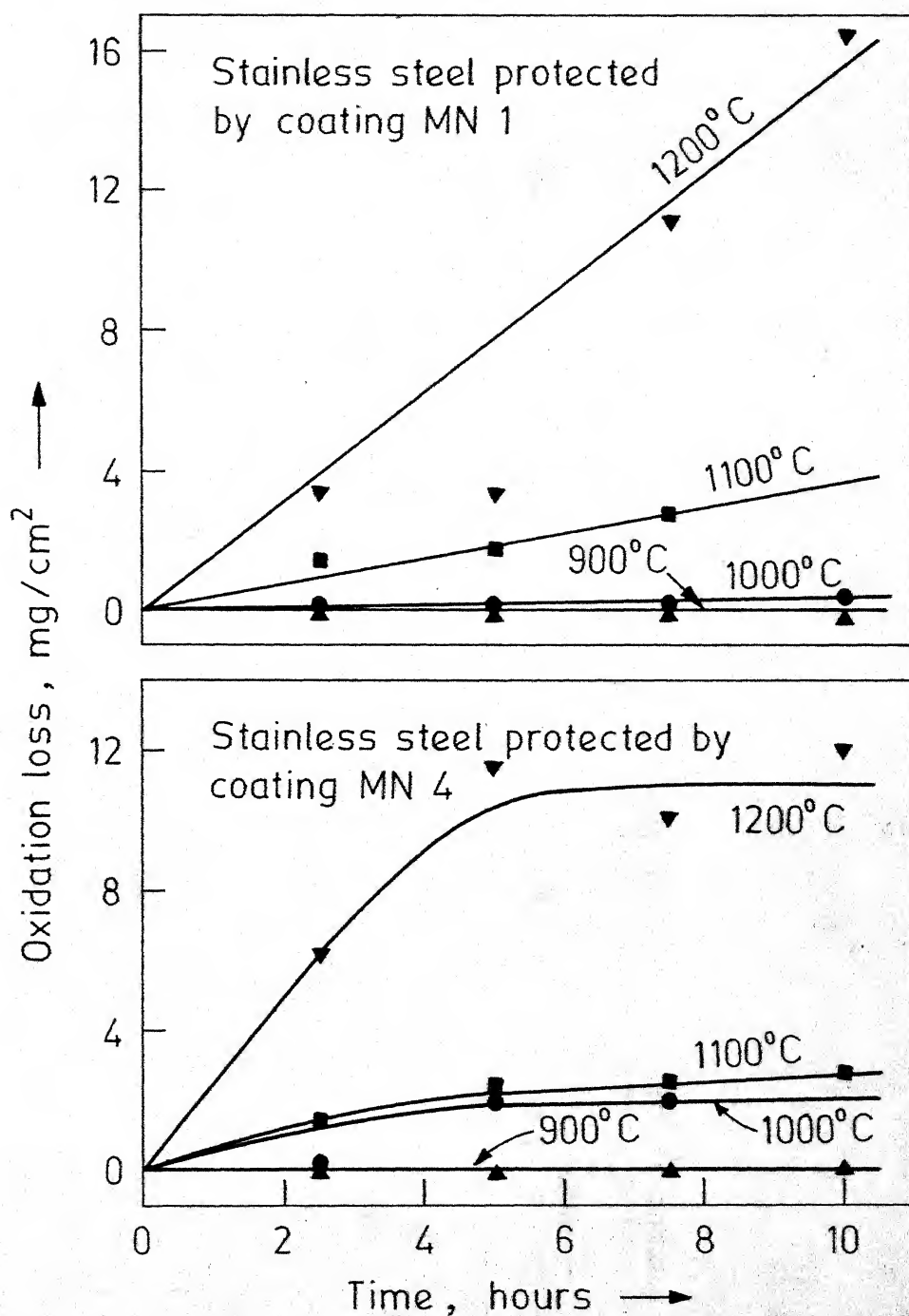
Fig. 7 Oxidation loss of stainless steel protected by coatings MN 1 and MN 4 at different temperatures and times.

Table 3.9

PERCENTAGE REDUCTION IN OXIDATION LOSS OF 18-8 STAINLESS STEEL

EXPOSED AT DIFFERENT TEMPERATURES AND TIMES USING COATINGS

MN1 AND MN4 *

Percentage Reduction in oxidation loss of stainless steel using

Time hrs.	Coating MN1 at				Coating MN4 at			
	900°C	1000°C	1100°C	1200°C	900°C	1000°C	1100°C	1200°C
2.5	100.00	99.81	97.02	95.49	100.00	98.91	97.08	91.80
5.0	100.00	99.49	95.83	96.48	100.00	92.31	95.53	89.86
7.5	100.00	98.49	95.86	92.66	100.00	91.14	96.63	93.44
10.0	100.00	98.41	92.67	89.74	100.00	89.02	96.88	91.15

* - 12 cc of binder 'S' having a specific gravity of 1.3 gm/cc was mixed with 20 gms of coating powder.

- Coated specimens were air dried for 6 hrs at room temperature before exposure at high temperature.
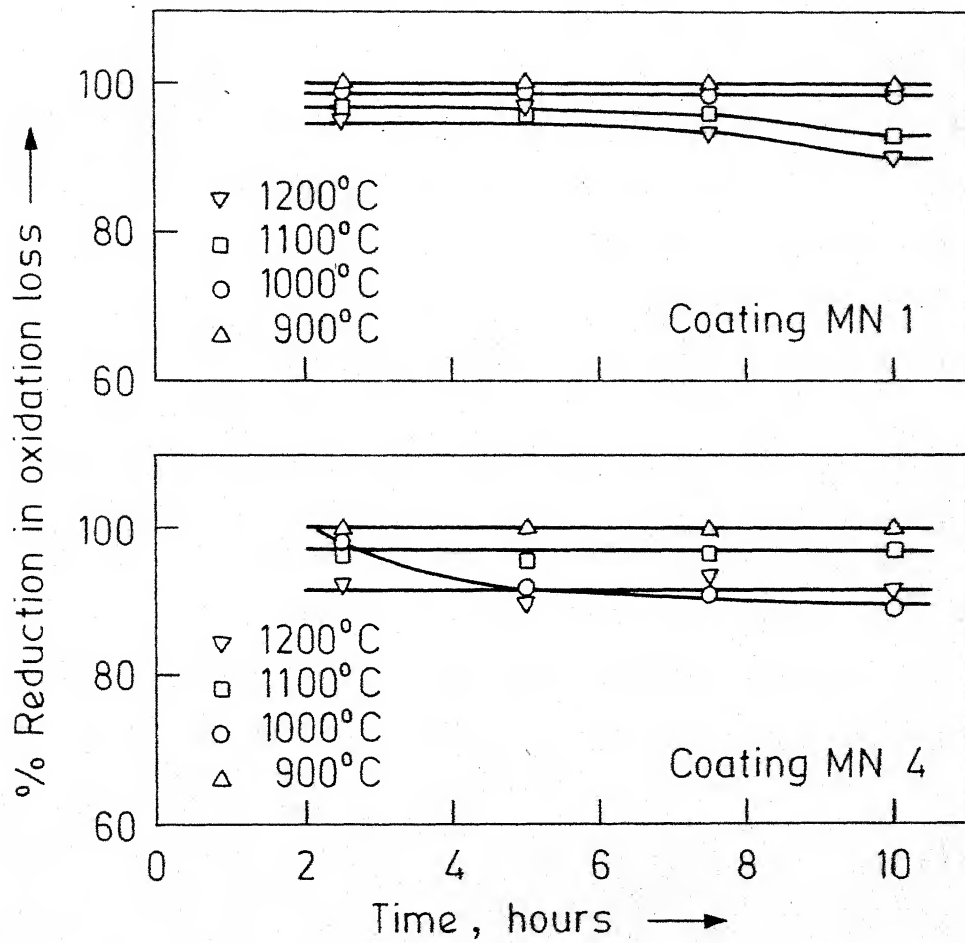
Fig. 8 Effect of coatings MN 1 and MN 4 in reducing
oxidation loss of tool steel at different temperatures
and times.

i) Both coatings MN1 and MN4 drastically reduced the oxidation loss of 18-8 stainless steel at all temperatures and times.

ii) It appeared that at all temperatures and times there was practically no difference in both the coatings, percentage reduction in oxidation loss being above 89 % in all cases.

3.5 OXIDATION PREVENTION OF TOOL STEEL

Effectiveness of coating compositions MN1 and MN4 using binder 'S' of 1.3 gm/c.c. specific gravity in preventing oxidation loss of tool steel at different temperatures for different times was determined.

Comparing oxidation loss of uncoated tool steel (Figure 9, Table 3.10) with tool steel coated with coating compositions MN1 and MN4 (Figure 10, Table 3.10) and percentage reduction in oxidation loss using these coatings (Figure 11, Table 3.11) following could be observed:

i) Coating - MN4 was very effective in reducing oxidation loss of tool steel at all temperatures and times, coating MN1 was effective at $900^{\circ}C$ and $1000^{\circ}C$ for all times. However at $1100^{\circ}C$ its effectiveness decreased with increasing time.

Table 3.10

OXIDATION LOSS OF TOOL STEEL AT DIFFERENT TEMPERATURES AND TIME WITH AND WITHOUT COATING*

Expt. No.	Composition Code	Time hrs.	Oxidation loss mg/cm^2 at Exposure Temperature		
			900°C	1000°C	1100°C
1	Uncoated	1.0	8.50	28.25	247.85
2	' '	2.0	29.94	102.64	280.64
3	' '	3.0	28.99	294.41	416.64
4	' '	4.0	94.76	318.91	426.25
5	' '	5.0	102.53	339.30	465.23
6	MN1	1.0	3.25	10.98	28.28
7	' '	2.0	8.97	14.86	50.24
8	' '	3.0	7.26	15.32	101.00
9	' '	4.0	10.23	16.21	163.89
10	' '	5.0	11.36	19.71	327.23
11	MN4	1.0	3.98	15.56	13.08
12	' '	2.0	7.42	18.42	17.06
13	' '	3.0	9.29	20.06	21.89
14	' '	4.0	9.64	22.45	32.05
15	' '	5.0	9.89	23.93	85.98

*   - 12 cc of binder S having a specific gravity of 1.3 gm/cc was mixed with 20 gms of coating powder.

    - Coated specimens were air dried for 6 hrs at room temperature before exposure at high temperature.
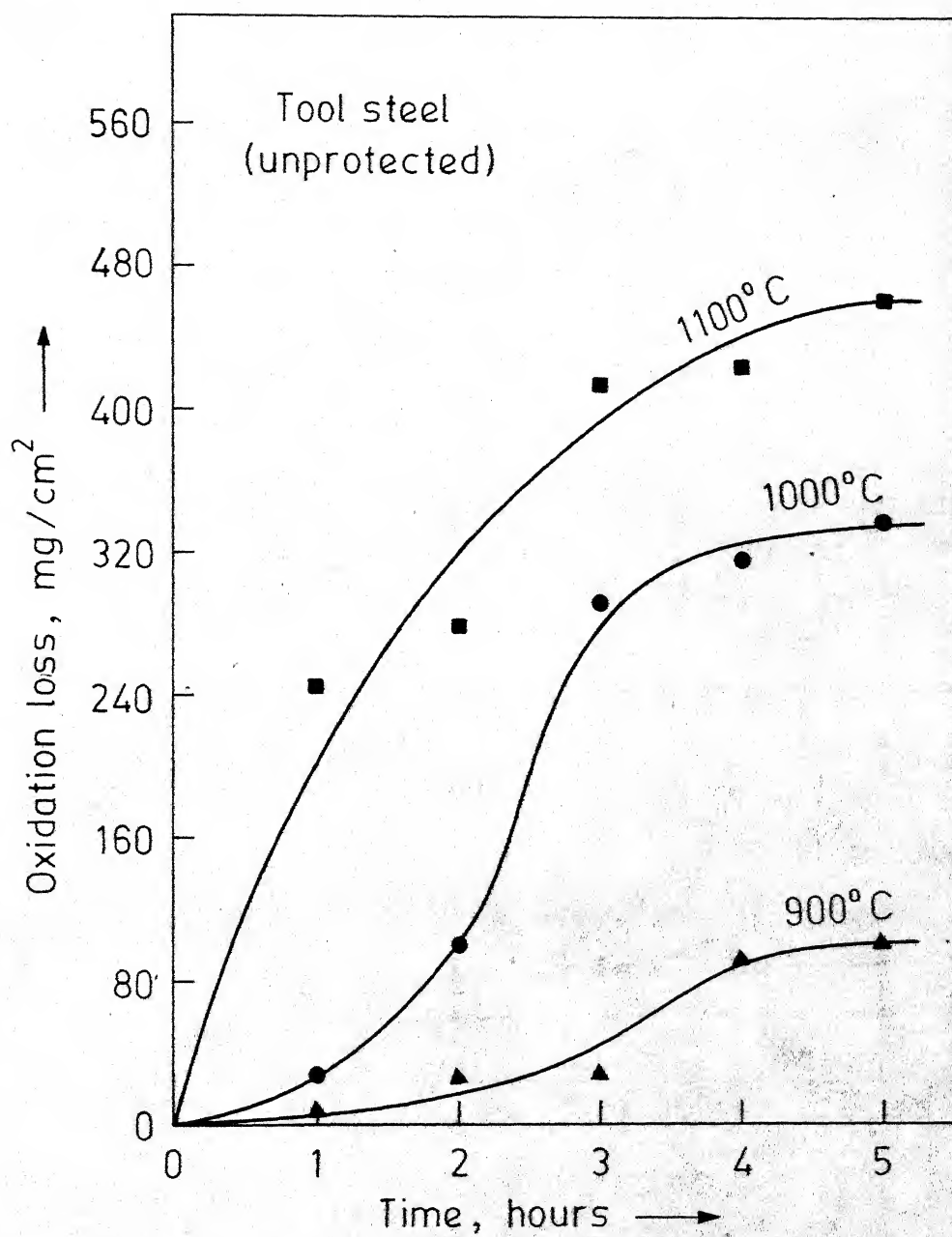
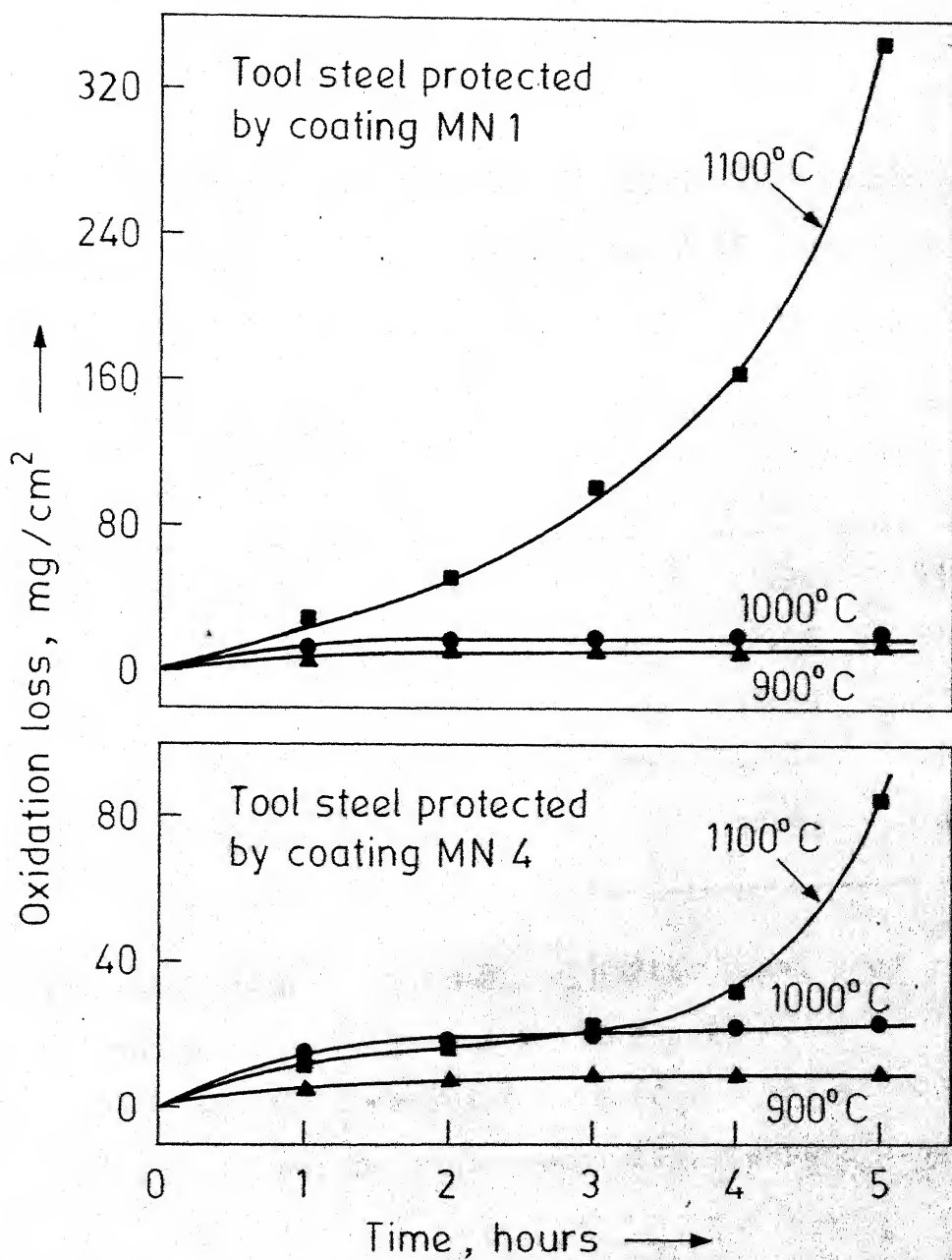Fig. 9 Oxidation loss of unprotected tool steel at different temperatures and times.

Fig. 10   Oxidation loss of tool steel protected by coatings MN 1 and MN 4 at different temperatures and times.

Table 3.11

PERCENTAGE REDUCTION IN OXIDATION LOSS OF TOOL STEEL

EXPOSED AT DIFFERENT TEMPERATURES AND TIMES USING

COATINGS MN1 AND MN4 *

Time hrs.	Percentage Reduction in oxidation loss of Tool Steel Using					
	Coating MN1 at			Coating MN4 at		
	$900^{\circ}C$	$1000^{\circ}C$	$1100^{\circ}C$	$900^{\circ}C$	$1000^{\circ}C$	$1100^{\circ}C$
1.0	61.76	61.13	88.59	53.18	44.92	94.72
2.0	70.04	85.52	82.10	75.22	82.05	93.92
3.0	74.96	94.80	75.76	67.95	93.19	94.75
4.0	89.70	94.91	61.55	89.83	92.96	92.48
5.0	88.92	94.19	29.66	90.35	92.95	81.52

*   – 12 cc of binder S having a specific gravity of 1.3 gm/cc was mixed with 20 gms of coating powder.

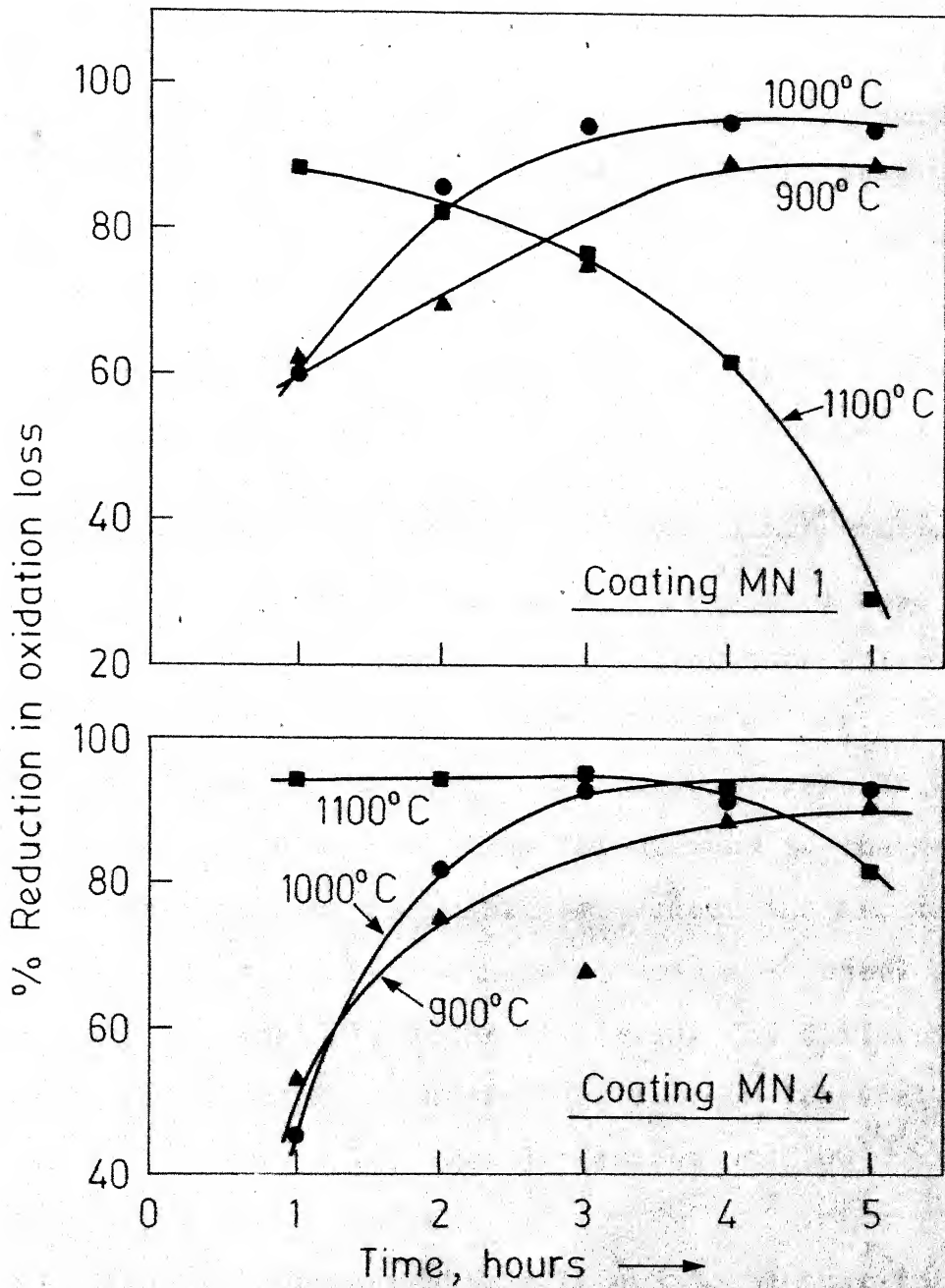   – Coated specimens were air dried for 6 hrs at room temperature before exposure at high temperature.

Fig. 11   Effectiveness of coatings MN 1 and MN 4 in reducing oxidation loss of tool steel at different temperatures and times.

ii) Effectiveness of the coatings in preventing oxidation, as judged by percentage reduction in oxidation loss increases with exposure time at $900^{o}C$ and $1000^{o}C$. At $1100^{o}C$ it decreased.

iii) It appears that for longer times at higher temperature coating MN4 is more effective than coating MN1.

3.6 EFFECT OF AIR DRYING TIME AND CHARGING TEMPERATURE

In the work described, so far the coated specimens were charged in the furnace at room temperature after air drying for 6 hours. In many cases, it may be desirable to charge the coated specimens at high temperature. This could however, result in coating failure due to thermal shock. It may also be desirable to reduce the air drying time. In order to evaluate these effects mild steel specimens coated with coating MN1, after air drying for different periods, were charged in the furnace at room temperature and at $1000^{o}C$. Oxidation loss was determined at $1000^{o}C$ after exposure for 5 and 10 hours.

It was observed (Table 3.12 and 3.13) that the oxidation loss of mild steel decreases with increasing air drying time on charing at either $1000^{o}C$ or at room temperature. As the air drying time is increasing more and more water from the coating gets evaporated which in turn reduces the possibility

Table 3.12

EFFECT OF AIR DRYING TIME AND CHARGING TEMPERATURE

ON THE OXIDATION LOSS OF MILD STEEL AT 1000°C.*

Coating Code	Charging Temp.	Oxidation Loss mg/cm^2							
		Exposed at 1000°C for 5 hrs				Exposed at 1000°C for 10 hrs			
		Air drying time hrs.				Air drying time hrs.			
		1	2	4	6	1	2	4	6
MN1	1000°C	19.72	16.70	10.95	7.30	47.02	74.57	68.11	12.23
"	Room Temp.	108.69	21.39	77.05	9.90	76.15	35.26	64.73	22.52

* - 12 cc of binder 'S' having a specific gravity of 1.3 gm/cc was mixed

with 20 gms of coating powder.

Table 3.13

PERCENTAGE REDUCTION IN OXIDATION LOSS OF MILD STEEL AIR DRIED FOR DIFFERENT PERIODS AND EXPOSED AT 1000°C FOR

5 Hrs and 10 Hrs *

Coating Code	Charging Temp.	Percentage Reduction in Oxidation Loss							
		Exposed at 1000°C for 5 hrs				Exposed at 1000°C for 10 hrs			
		Air drying time hrs				Air drying time hrs			
		1	2	4	6	1	2	4	6
MN1	1000°C	87.02	89.01	92.18	95.20	88.02	81.29	82.91	96.71
"	Room Temp.	28.32	85.92	49.28	93.49	80.89	91.15	83.76	94.35

* = 12 cc of Binder 'S' having a specific gravity of 1.3 gm/cc was mixed

with 20 gms of coating powder.

of coating dammage during firing because of sudden moisture
evaporation. This would explain the benificial effect of air
drying for longer times. Although the oxidation loss after
air drying for 1 hour was more than the loss after air
drying for 6 hours, however, it still represented a reduction
in oxidation loss of 87% for 5 hrs exposure and 88% for 10
hrs at 1000°C as compared to uncoated specimens. This may
be more than adequate for many industrial applications.

Charging at 1000°C showed less oxidation loss in
most of the cases. It may be because, while charging at
room temperature the poracity of the coating is more, till the
coating becomes viscous enough to fill the pores. But in
case of charing at 1000°C the coating becomes viscous and fills
the pore immediately on charging, thereby reducing the time
for which the specimens remain practically unprotected. This
results in lower oxidation loss in cases when the specimens
are charged in the furnace at 1000°C as compared to charging
in furnace at room temperature and raising the temperature
afterwords.

3.7 THERMAL CONDUCTIVITY OF THE COATING

Ideal coating should have good thermal conductivity.
Since, poor conductivity would mean that the time taken by
the coated specimen to attain the furnace temperature would be
different than the uncoated specimen. Therefore, adjustments

will have to be made in the normal heat treatment cycle.
However, if the thermal conductivity of the coating is good,
then, such coating could be used without altering the
conventional heat treatment cycle.

To evaluate the thermal conductivity of the coating
and the time taken to attain the furnace temperature at the
centre of mild steel specimen, 2.5 cm (dia) x 5 cm (long), in
coated and uncoated conditions.

Three specimens, one without coating and the other
two with coating MN1 and MN4 were charged in the furnace at
room temperature and the temperature has been raised. The
temperatures of the specimens were measured after 5 minutes
interval. The results clearly show that there was practically
no difference in temperature of coated and uncoated specimens
indicating both the coatings have good thermal conductivity
(Figure 12).

3.8 EFFECT OF COATING ON THE HARDENING TREATMENT FOR STEELS

As stated earlier, an ideal coating should not hinder
the normal heat treatment process so that it could be used
without altering the conventional heat treatment processes.

To evaluate the effect of coating on material harden-
ability two specimens one without coating and the other with
coating MN1 were austenitized at 1000°C for 1 hr followed by
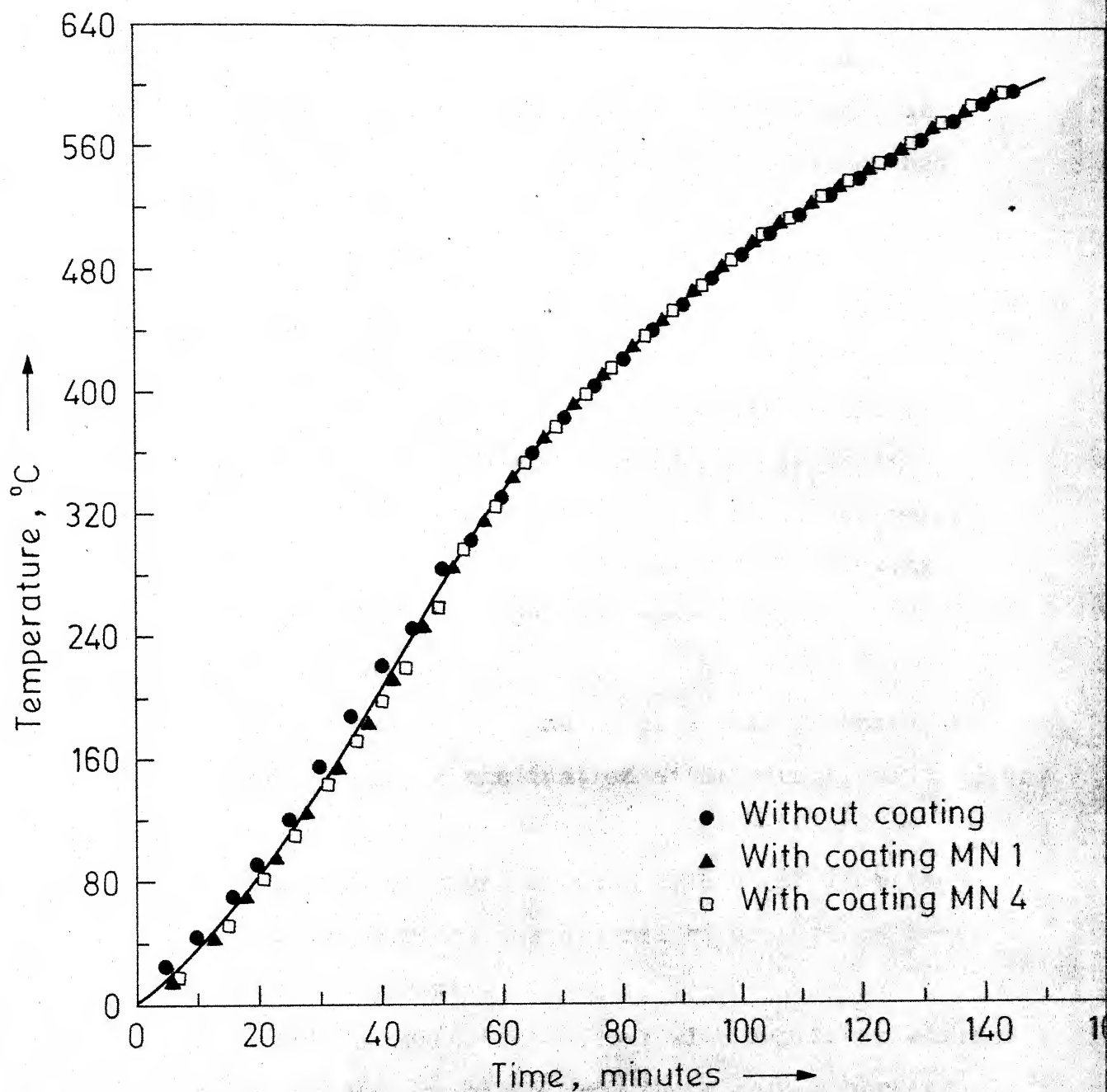water quenching. Microhardness at 0.127 mm interval was

Fig. 12 Rise in temperature at the cente of 25 mm diameter mild st specimen without coating and with coatings MN 1 and MN 4.

measured on a cross section of each of the specimens. The results show that there was practically no difference in hardness of coated and uncoated specimens indicating that the coating is not hindering the hardening treatment (Figure 13, Table 3.14).

3.9   PREVENTION OF DECARBURIZATION

As mentioned earlier, an ideal coating should also prevent decarburization of steels during heat treatment process. To evaluate this effect, the extent of decarburization, in a 0.56% carbon steel studied by the following methods for coated and uncoated specimens exposed at $1000^{\circ}C$ for 10 hrs followed by air cooling,

i) A cross section of the specimen was prepared for metallographic examination after etching with 5% Nital.

ii) Variation of microhardness with depth from the specimen surface was determined on a cross section of each specimen.

iii) Variation of carbon content with depth was studied by removing turnings from the specimen surface in steps of 0.127 mm upto a depth of 1.143 mm. These turnings were analysed for carbon content using Strohleim apparatus.

Table 3.14

EFFECT OF COATING ON HARDENING TREATMENT OF A 0.56% C STEEL SPECIMEN AUSTENITISED AT 1000°C FOR 1 Hr FOLLOWED BY WATER QUENCHING

| Distance from surface mm	Microhardness D.P.N.	
	Uncoated	Coated with MN1
0.00	575.6	570.00
0.13	570.0	565.0
0.25	565.6	557.5
0.38	552.5	547.5
0.51	537.5	527.5
0.64	516.4	512.5
0.76	441.2	441.2
0.89	401.2	401.2
1.40	376.4	376.4
1.91	344.4	344.4
2.42	344.4	344.4
3.00	344.4	344.4
3.58	344.4	344.4
4.09	344.4	344.4
4.60	376.4	376.4
5.11	401.2	401.2
5.24	441.2	441.2
5.37	516.4	512.5
5.50	537.5	527.5
5.63	552.5	547.5
5.76	565.6	557.5
5.89	570.0	565.0
6.00	575.6	570.0
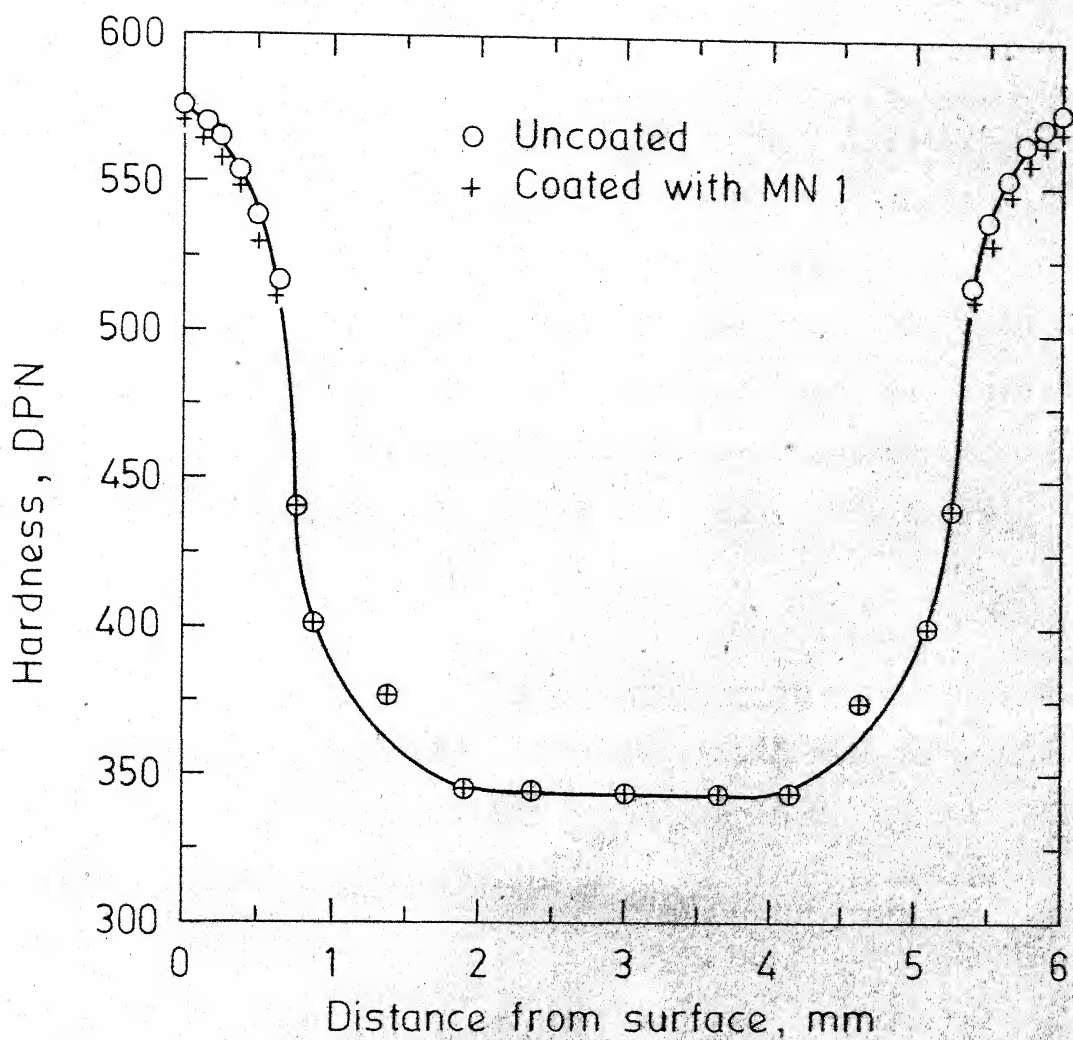
Fig. 13 Effect of coating MN 1 on the hardenability of 0.56 % carbon steel specimen austenitized at 1000° C for 1 hour followed by water quenching.

Taking into consideration the loss in specimen
thickness during exposure due to oxidation it could be
seen that in coated specimen both hardness and carbon
content (Figure 14) attained the value of the parent material
in annealed condition at a lesser depth than the uncoated
specimen. This indicated that the coating MN1 was helping
in preventing decarburization. This fact was also borne
out by the photomacrographs of the cross-sections of coated
and uncoated specimens after the heat treatment cycle
(Figure 15, Table 3.15 and 3.16).

3.10   SURFACE COVERING ABILITY OF THE COATING

20 gms of coating powder was mixed with 12 cc of
binder and coated on the mild steel specimens and the weight
of powder plus binder required to cover 1 m² area was
calculated as follows.

Weight of the uncoated specimen (W_1) = 12.3298 gms
Weight of the coated specimen (W_2) = 16.3021 gms
Specimen surface area (A) = 50.96 cm^2
Weight of 12 cc of binder (W_3) = 15.6 gms
Weight of powder used (W_4) = 20.0 gms

Weight of powder + binder
to cover 50.96 cm² surface   = $W_2 - W_1$
area   = 3.9723 gms

Table 3.15

VARIATION OF MICROHARDNESS WITH DEPTH IN 0.56% C
STEEL SPECIMENS, UNCOATED AND COATED WITH MN1,
AFTER HEATING AT 1000°C FOR 10 Hrs FOLLOWED BY
AIR COOLING

Uncoated		Coated with MN1	
Distance from surface mm	Micro-hardness D.P.N.	Distance from surface mm	Microhardness D.P.N.
1.07	85.2	0.66	161.0
1.19	110.2	0.79	92.4
1.32	78.0	0.91	137.2
1.45	106.6	1.04	154.4
1.57	161.0	1.17	168.0
2.08	168.0	1.68	93.4
2.59	168.0	2.18	148.4
3.10	168.0	2.69	168.0
3.61	168.0	3.26	168.0
4.11	168.0	3.71	168.0

Table 3.16

VARIATION OF CARBON CONTENT WITH DEPTH IN 0.56% C
STEEL SPECIMENS, UNCOATED AND COATED WITH MN1,
AFTER HEATING AT 1000°C FOR 10 Hrs FOLLOWED BY
AIR COOLING

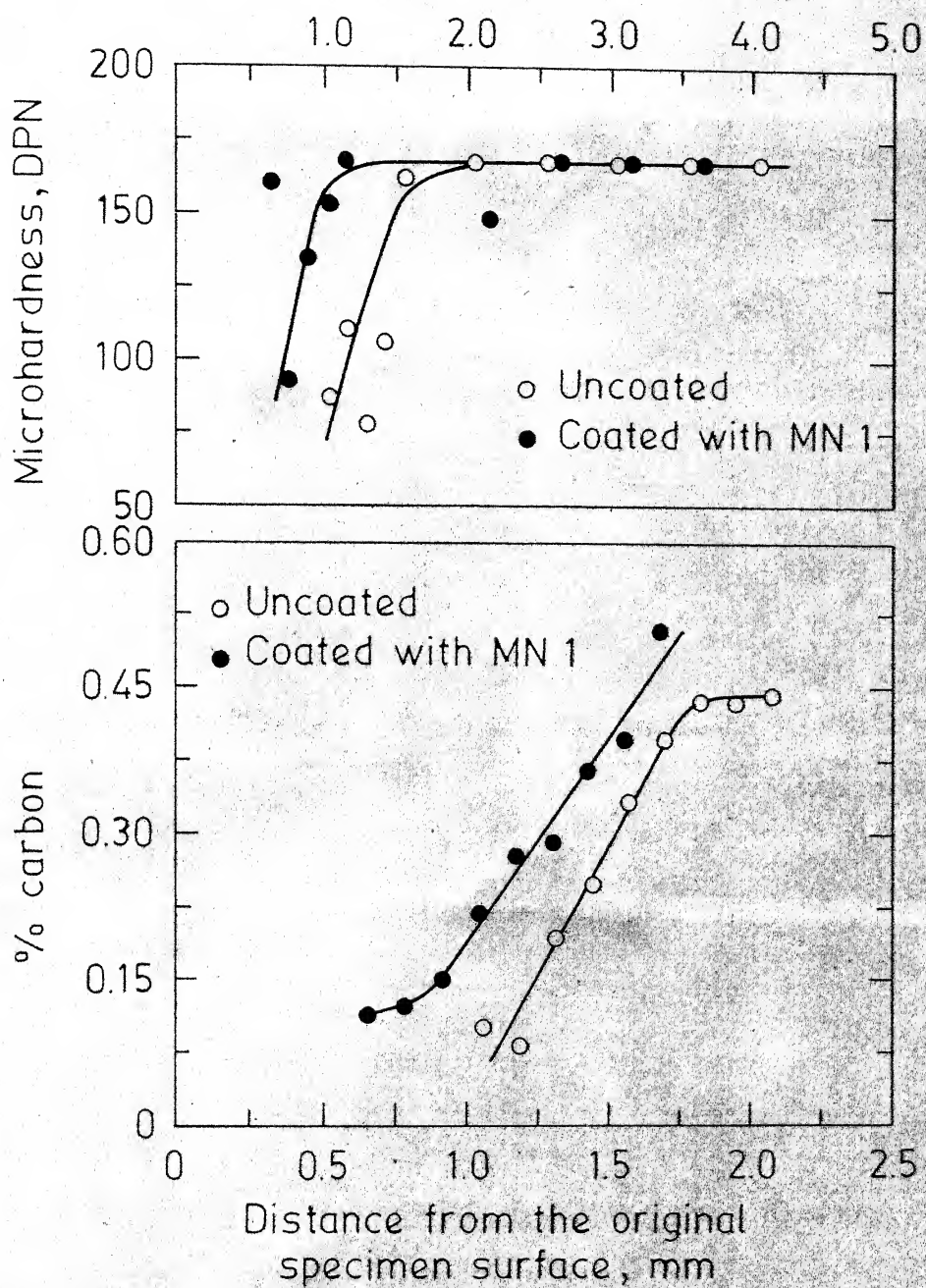| Uncoated		Coated with MN1	
Distance from surface mm	Carbon percentage	Distance from surface mm	Carbon percentage
1.07	0.10	0.66	0.11
1.19	0.08	0.79	0.12
1.32	0.19	0.91	0.15
1.45	0.25	1.04	0.22
1.57	0.33	1.17	0.28
1.70	0.40	1.30	0.29
1.83	0.44	1.42	0.35
1.96	0.43	1.55	0.40
2.08	0.44	1.68	0.51

Fig. 14 Variation of microhardness and carbon content with depth in 0.56 % carbon steel specimens, uncoated and coated with MN 1, after heating at 1000° C for 10 hours followed by air cooling.
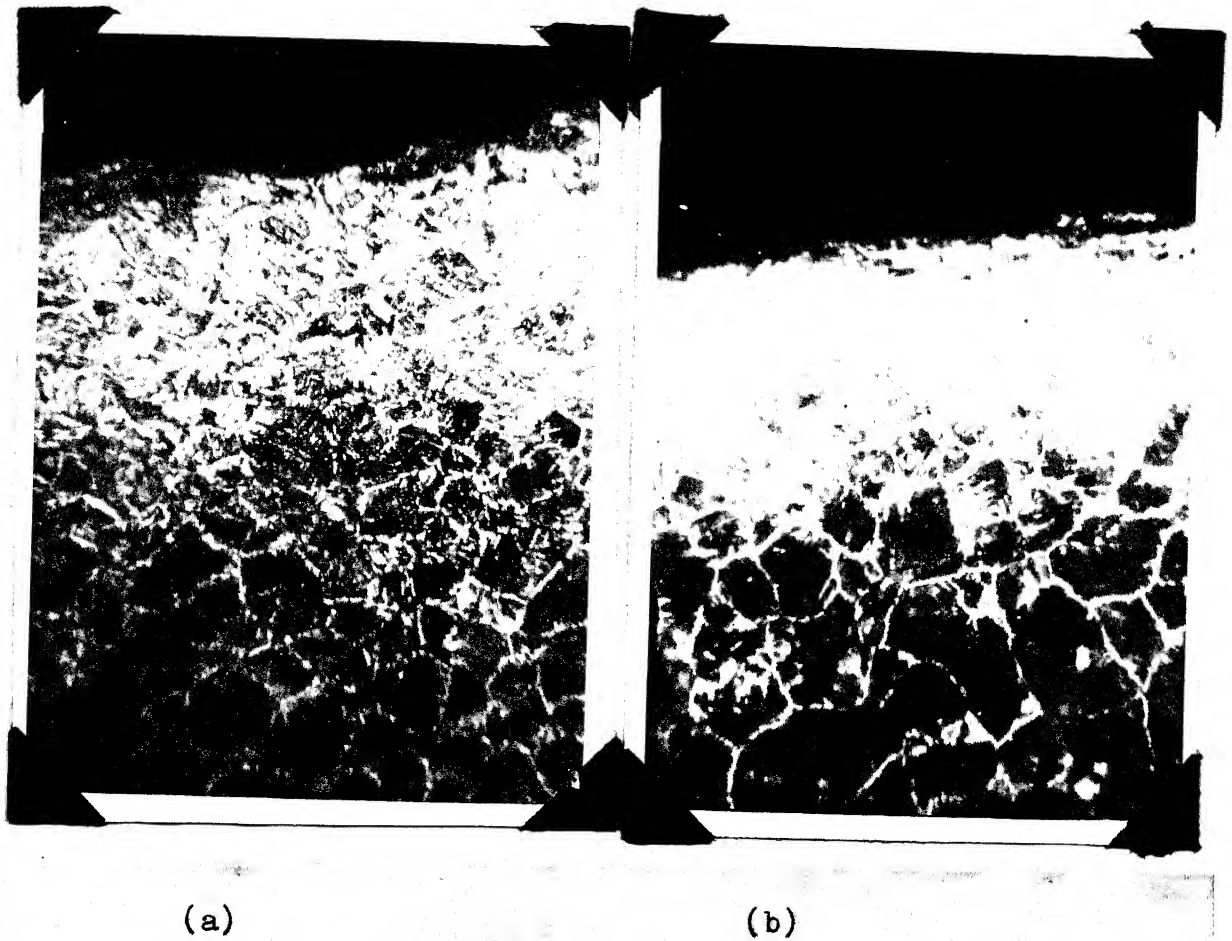
(a)　　　　　　　　　　(b)

Fig. 15: Microstructures showing the decarburized
layers in (a) uncoated and (B) coated with
MN1 specimens of 0.56% C steel exposed at
1000°C for 10 hrs. (150X).

Weight of powder + binder
to cover 1 m^2 surface area

$$= \frac{10^4}{A} \times (W_2 - W_1)$$

$$= \frac{10^4 \times 3.9723}{50.96}$$

$$= 779.49 \text{ gms}$$

Weight of powder out of
779.49 gms of binder + powder

$$= \frac{779.49}{W_3 + W_4} \times W_4$$

$$= \frac{779.49 \times 20.0}{15.6 + 20.0}$$

$$= 437.91 \text{ gms}$$

Weight of binder

$$= 779.49 - 437.91$$

$$= 341.58 \text{ gms}$$

Volume of 341.58 gms of binder
solution

$$= \frac{341.58}{W_3} \times 12$$

$$= \frac{341.58}{15.6} \times 12$$

$$= 262.75 \text{ cc}$$

To cover 1 m^2 surface area 437.91 gms of powder and
262.75 cc of binder solution would be required.
Or in other words 20 gms of powder and 12 cc of binder
solution mixed together would cover about 450 cm^2 surface
area.

3.11 COST OF COATING

The cost of coating has been calculated on the basis of present raw material cost without grinding and labour charges as follows.

Raw Materials Cost

Material 'A'	Rs. 500/Ton
Material 'B'	Rs.2000/Ton
Material 'C'	Rs. 500/Ton
Material 'D'	Rs. 500/Ton
Material 'E'	Rs. 500/Ton
Binder 'S'	Rs.2000/Ton

To get 1.3 gm/cc specific gravity of binder solution 75 gms of binder was added to 100 cc of water.

Total volume of the binder solution i.e. 75 gms of binder + 100 cc of water = 110 cc

To cover 1 m^2 surface area volume of biner required = 262.75 cc

Weight of the Binder added to get 262.75 cc of solution = $\frac{262.75}{110}$ x 75

= 179.15 gms

The cost of 10 Kg of coating MN1 powder (in the proportion as given in Table 3.3) = Rs. 10.55

The cost of 10 Kg of coating MN4 powder (in the proportion as given in Table 3.3) = Rs. 8.76

The price of 179.15 gms of the binder $\qquad = Rs. \dfrac{179.15}{10^5} \times 2000$

$= Rs. \ 0.36$

To cover 1 m² surface area required powder $\qquad = 437.91$ gms

The price of 437.91 gms coating MN1 $\qquad = Rs. \dfrac{437.91}{10^4} \times 10.55$

$= Rs. \ 0.46$

Similarly the price of 437.91 gms of coating MN4 $\qquad = Rs. \ 0.38$

The price of coating MN1 powder + binder 'S' to cover 1 m² surface area $\qquad = Rs. \ (0.46 + 0.36)$

$= Rs. \ 0.82$

Similarly the price of coating MN4 powder + binder 'S' to cover 1 m² surface area $\qquad = Rs. \ (0.38 + 0.36)$

$= Rs. \ 0.74$

3.12 REMOVAL OF THE COATING AFTER EXPOSURE

The surface coatings for heat treatment process ideally should have the properties stated in section 1.3. Two important properties are it should come off by itself from the specimen surface and it should not react with the specimen surface when exposed at high temperatures.

It was observed (Table 3.17) that both coatings MN1 and MN4 came off by themself during cooling of the specimen after exposure at high temperature and also they are not

TABLE 3·17 SURFACE APPEARANCE OF UNPROTECTED AND PROTECTED SPECIMENS AFTER EXPOSURE AT DIFFERENT TEMPERATURES AND TIMES.

Coating code	MILD STEEL Exposure time hrs	Exposure temperature °C 700	900	1100	STAINLESS STEEL Exposure time hrs	Exposure temperature °C 900	1000	1100	1200	TOOL STEEL Exposure time hrs	Exposure temperature °C 900	1000	1100
NIL (Uncoated specimen)	2.5	D	E	F	2.5	E	E	E	E	1.0	E	F	F
	5.0	D	E	F	5.0	E	E	E	E	2.0	F	F	F
	7.5	E	E	F	7.5	E	E	E	E	3.0	F	F	F
	10.0	E	F	F	10.0	E	E	E	E	4.0	F	F	F
										5.0	F	F	F
MN 1	2.5	B	B	D	2.5	A	B	B	B	1.0	B	B	B
	5.0	C	C	D	5.0	A	B	B	B	2.0	B	B	B
	7.5	C	D	D	7.5	A	B	B	C	3.0	B	B	D
	10.0	D	C	D	10.0	A	B	B	C	4.0	B	B	E
										5.0	B	B	D
MN 4	2.5	C	C	D	2.5	A	B	B	B	1.0	B	B	B
	5.0	C	D	D	5.0	A	B	B	B	2.0	B	B	B
	7.5	C	F	D	7.5	A	B	B	C	3.0	B	B	B
	10.0	C	F	D	10.0	A	B	B	C	4.0	B	B	E
										5.0	B	B	D

REMARKS

1 12 cc of binder 'S' having a specific gravity of 1.3 gm/cc was mixed with 20 gm of coating powder.

2 Coated specimens were air dried for 6 hours at room temperature before exposure at high temperature.

3 In all cases the coating surface after 6 hours of air drying was even and showed no cracks, indicating good paitability and adequate adherence to the base.

4 In all cases the coating came off from the specimen surface by it self on cooling after firing at high temperature.

5 Surface appearance code : (A) Practically no oxidation   (B) Slight oxidation without pitting   (C) Temper colours appeared on the surface without pit formation   (D) Light gray colour with slight pits formation   (E) Dark black coloured oxidation layer which came off as flakes   (F) Dark grey colour with heavy pitting.

reacting with the specimen surface. The coatings come off by itself because the coefficient of thermal contraction of the base metal and the coating was different. The metal contracts more rapidly than coating. So stresses develope in the coating and the bond between the specimen surface and coating breaks. Because of this the coating comes off by itself.

CHAPTER IV

CONCLUSIONS

The following conclusions can be drawn from the results which were shown in Chapter III:

1. Both coatings MN1 and MN4 are very effective in reducing the oxidation loss of mild steel and stainless steel. The percentage reduction in oxidation, in comparison to uncoated specimens, of mild steel and stainless steel is above 69% and 89% respectively at all temperatures and times. In case of tool steel coating MN4 is more effective than coating MN1 at all temperatures and times.

2. In case of mild steel and stainless steel the percentage reduction in oxidation with coatings MN1 and MN4 increased with time at all temperatures. But in case of tool steel at 1100°C the effectiveness of both the coatings MN1 and MN4 decreased with time.

3. For longer exposure the coating MN4 showed better protection to oxidation than coating MN1 in all steels.

4. The application of both the coatings is easy by brush painting. It would be possible to adjust the fluidity of the coating so that it could be applied by dip or spray coating methods also.

5. During cooling, after exposure at high temperature, both the coatings came off the specimen surface by itself.

6. Both the coatings showed good thermal conductivity.

7. Coating MN1 reduced the amount of decarburization and does not hinder the normal hardening treatment of steel. It is expected that coating MN4 will behave in a similar manner.

8. The surface covering power of the coatings is good. 20 gms of the coating powder mixed with 12 cc of the binder would cover about 450 cm^2 surface area.

9. Coating MN1 and MN4 are cheap. Based on raw material costs only it would cost about Rs. 0.82 for coating MN1 and Rs. 0.74 for coating MN4 to cover about 1 Sq. Meter surface area.

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